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ENERGY OUTPUT EVALUATION FROM A PHOTOVOLTAIC SYSTEM AT DIFFERENT SELECTED SITES IN JORDAN

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ABSTRACT

Solar energy is one of the best solutions for Jordan energy problems, as Jordan is a sunny country with 300 sunny days over the year. This study presents a calculation of the energy output from a PV system at six selected sites in Jordan: Ajloun (32˚ N, 36˚ E), Salt (32˚ N, 36˚ E), Madaba (32˚ N, 36˚ E), Karak(31˚ N, 36˚ E), Tafelh(31˚ N, 35˚ E) and Maan(30˚ N, 35˚ E). The paper studies the radiation data of the sun with the ambient temperature, in order to make a comparison of the energy output from the selected sites. The result showed that Madaba and Maanare the optimum sites for the PV application investment comparing to the other sites.

KEYWORDS: PV Systems, Radiation & Energy Output

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Original Article

INTRODUCTION

Jordan depends on the imported fuel in order to satisfy the needs of energy, as Jordan didn't have national oil resources with a percentage guide to independence on the imported fuel as what Jordan has is only coves not more 3-4% of what the country needs [1-10]. The energy demand in Jordan is rising sharply as it is expected that Jordan will need a double energy amount over the tenth year from now. Thus, will lead to producing more unfriendly emissions. For that, looking after new energy sources becomesessential [1, 4, 11-19].

Nowadays, photovoltaic (PV) systems consider one of the exultant solution from the renewable energy types to ensure the amount of energy required for different application as well as to participate partially to cover the needs of the electricity[9-11, 13-17, 20-26]. PV system has several advantages make it a good choiceto invest in, such as: the direct converting of the solar radiation to electricity due to simple parts, PV system didn't have a movable part which makes the durability of the system is high and the maintenance is easy, PV system didn't depend on the firing so it is pollutant free, long life cycle and finally easy to establish. The energy production of the PV strongly depend on the availability of the radiation comes from the sun and the performance of the system. Thus, make the cost of production from the PV system varies from site to other sites. As a result, encouraging PV system insulation will help in more environmentally friendly electricity generation and reducing the energy production cost[27-36].

Studying the ability of the electricity generation from The PV system at different sites all over the world is a hot topic where several researchers working on. Alnajedean and Saad present a case study to design and evaluate the performance of a PV system for the school of engineering at Mutah University in order to cover the electricity needs of the school[37]. Alrwashdeh presented a study to evaluate the energy production from a PV system at three different sites in Jordan, where it was found that Aqaba governorate has the maximum energy production among the

selected sites, that because Aqaba governorate has the maximum solar radiation between the selected sites[20]. Hammad et al. present a case study about using the PV system in order to reduce the electricity cost for a school in Amman-Jordan, and they found by using the PV system the electricity cost will reduce by a half of the old value of the traditional electricity from the national grid[38].

Scientists from all over the world study the using of the PV system over the head of the building and in the remote location from the landscape. They found that the use of the PV system over the building is more convenient as all area of the building will invest as well they will avoid the shading effect from the building in case that the PV system is built near it[2, 27, 37-39].

Recently, Jordan policy is to encourage the energy mix between the traditional energy production ways and the renewable energy systems. An example of encouraging the energy mix in Jordan, the strategic plan of the energy in Jordan says that 20% of the national needs will depend on renewable energy by the end of 2020[1, 40].

The previous studies discussed the situation of the energy in Jordan and what is the possible ways to improve the situation. In this study, the energy production from a PV system is studied for six different sites in Jordan which are: Ajloun, Salt, Madaba, Karak, Tafelh and Maan in order to specify where the best location for the PV application in Jordan is.

SITES DATA

Six sites in Jordan were selected for this study covering all part of the country north (Ajloun, Salt), middle (Madaba) and south (Karak, Tafelh and Maan) with an average elevationbetween 50 and 1200m above sea level. The selected sites are marked in the Jordan map in figure 1. Table 1 shows information for the selected sites about the solar radiation and the ambient temperature. The provided information gathered over a period of 10 years.

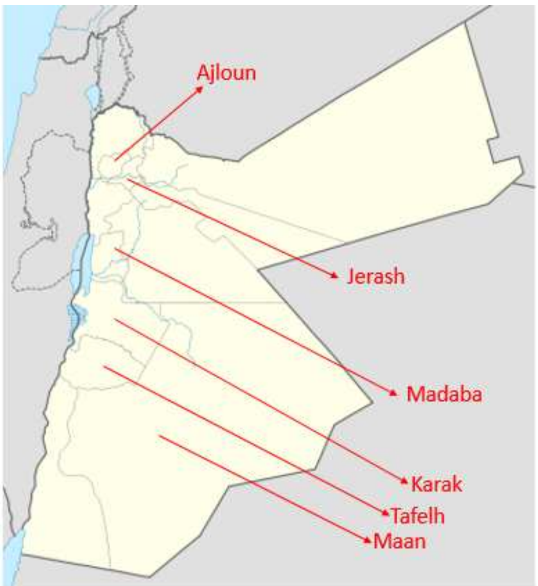

Figure 1: Jordan Map with the Sit Selected Sites of the Study[41]

Table 1: Monthly AVG Global Radiation kWh/m^2/Day and and Sites Yearly Temperature[42]

Mo	Monthly Average Global Radiation (kWh/m^2/day)						Sites Yearly Temperature					
	Ajloun	Salt	Madaba	Karak	Tafelh	Maan	Ajloun	Salt	Madaba	Karak	Tafelh	Maan
Jan	3.7	4.1	4.5	4.4	4.3	5.4	9	9	10	9	7	7
Mar	4.1	4.6	5	4.9	4.9	6.3	10	10	11	10	8	8
Apr	5.6	6	6.4	6.3	6.3	7.5	12	12	13	12	11	11
May	6.2	6.5	6.7	6.7	6.7	7.1	16	16	17	16	15	16
Jun	7	7.1	7.1	7.2	7.1	7.2	20	20	21	20	19	20
Jul	7.5	7.6	7.5	7.5	7.5	7.5	23	23	25	23	22	23
Aug	7.5	7.6	7.5	7.5	7.4	7.4	25	25	26	25	24	25
Sep	7.5	7.5	7.5	7.5	7.4	7.5	25	25	26	25	24	25
Oct	7	7.2	7.3	7.2	7.1	7.3	24	24	25	23	22	23
Nov	6.1	6.4	6.7	6.6	6.3	6.9	21	21	22	21	19	19
Dec	4.8	5.2	5.4	5.4	5.2	5.9	15	15	17	15	14	13

ESTIMATION ENERGY PRODUCTION

In the PV system, the PV module is the electricity generator. The PV module consists of PV solar cells connected together in different ways. The PV cell has a small area of about a few square centimeters. The performance of the PV system depends on the efficiency of the PV module which is the ratio between solar radiation and the power output. Recently, PV modules reach more than 25 % as efficiency which makes it a good way to invest to generate the required electricity.

In this study, LG PV module is selected which has an efficiency of 17.4% and a power output as the maximum of 340W that when the radiation reaches 1000 W/m^2 and area of 2m^2. The technical specification of the selected PV module is presented in the table. 2 note that the specification is measured under the standard test condition.

Table 2: The Technical Specifications of the PV Module [43]

Characteristics	Value	Units
Max power (P_{max})	340	W
Max power voltage (V_{pm})	37.7	V
Max power current (I_{pm})	9.02	A
Open circuit voltage (V_{oc})	46.4	V
Short circuit current (I_{sc})	9.54	A
Module Dimensions	1960 x 1000	mm
Temp. Coeff. of P_{max}	-0.420	%/°C
Temp. Coeff. of V_{oc}	0.335	V/°C
Temp. Coeff of I_{sc}	-0.047	mA/°C
Operating Module Temp.	-40 To 85	°C

The mathematical model was calculated based on the following equations related to the PV systems.

The max power output (P_{max}) of the PV module [44].

$$P_{\max\,(G,Tc)} = I_{SC}(G)\ \times V_{OC}(Tc)\ \times FF \qquad (1)$$

Where I_{sc} is short circuit current, V_{oc} is open circuit voltage, and FF is fill factor. Fill factor is the ratio between the max real power output and the theoretical max power output. Given as:

$$FF = \frac{P_{max}}{I_{SC}V_{OC}} = \frac{I_{pm}V_{pm}}{I_{SC}V_{OC}} \qquad (2)$$

whereI$_{pm}$ is electrical current at max power and V_{pm} is voltage at maxpower.

Based on Eq. 1, the short circuit current is direct proportional to the irradiance (G) additionally the open circuit voltage is direct proportional to the cell temperature (Tc). Given as [18]:

$$I_{SC}(G) = I_{SC}\left(when\ 1\ {kW}/{m^2}\right) \times G\ \left(in\ {kW}/{m^2}\right) \tag{3}$$

$$V_{OC}(Tc) = V_{OC} - 0.0023\ \times Number\ of\ cells\ \times (Tc - 25) \tag{4}$$

The cell temperature (Tc) is determined by

$$T_C = T_a + \frac{NOCT-20}{0.8} G\left({kW}/{m^2}\right) \tag{5}$$

Where NOCT is the normal operating cell temperature (usually between 42 and 46 ˚C), and Ta is ambient temperature [18].

The measurement system of the PV power is shown in firure.2.

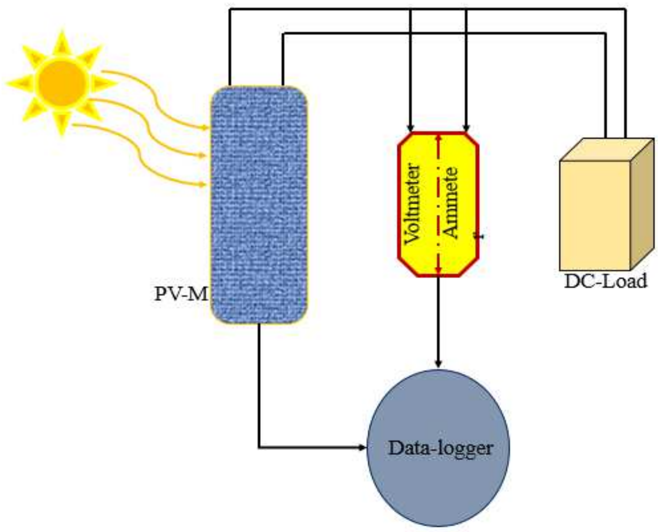

Figure 2: Measurement System of PV Module

The measurements system of the PV module power starts with devices to measure the open circuit voltage and the short circuit current which are: voltmeter as well ammeter and DC-load. The output power i.e. the DC load needs to be equal or greater the max PV power capacity that to ensure of the consumption of all PV power as well to aid in transfer the electricity to the electrical grid. The weather station is used to register the data of the climate for the selected sites. In order to measure the PV average temperature a thermocouple is used which is installed in the top, bottom, inserted in between of the PV glasses and over the surface of the PV module. Finally, all data gathered by using the data logger and stored in a computer server over the period of one year.

RESULTS

The power output of the PV module effected by several parameters such as the surrounding temperature, the PV system efficiency, the selected sit and finally on the radiation received from the sun. In this work, a same PV module is used at the six selected sites to study the power output from the sites and to select the best one for the PV investments. In order to measure the PV output power, several parameters measured like the circuit current and voltage. The mathematical model based on the previous equations is used.

Figure 3 shows the current as short circuit current of the selected six sites over the year. It is noted that the average max current of the sites was during June with values of 3.05 A for Ajloun, 3.25 A for Salt, 3.66 A for Madaba, 3.66 A for Karak, 3.66 A for Tafelh and 3.66 A for Maan. While the min values of the current were in January with a range between 1.5 and 2.5 A.

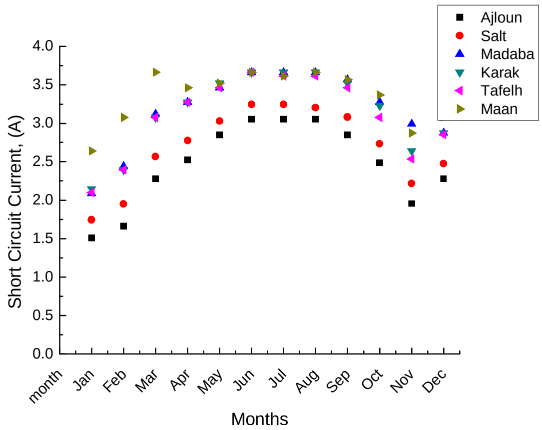

Figure 3: Average Short Circuit Current of the PV Module of the Six Selected Sites

In order to calculate the open circuit voltage, the cell temperature for the selected sites is needed as the voltage affected of it which is clear from equation number 4. The cell temperature is calculated based on the ambient temperature for the six selected sites by using equation number 5. The ambient temperature is illustrated in table.1 for the selected sites.

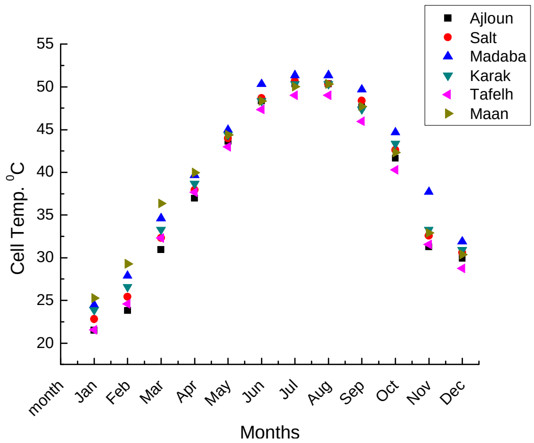

Figure 4: PV Module Average Cell Temperature of the Six Selected Sites

The cell temperature over the year for the selected sites is presented in figure 4. The max cell temperature for the selected sites: Ajloun, Salt, Madaba, Karak, Tafelh and Maanis: 50, 51, 51, 50, 49 and 50 ˚C. While the min cell temperature is: 22, 23, 24, 24, 22 and 25 ˚C, respectively. The max cell temperature was during July and the min was during January for the selected sites. The open circuit voltage is presented in the figure 5 for the six selected sites. It is noted that the max open circuit voltage for all of the sites is 46 V. While the min is 44 V for all selected sites as well. In the six selected sites, the max open circuit voltage was during January that because the ambient temperature is the min over the year, and the min values of the open circuit voltage were during July that because the ambient temperature is the max over the year.

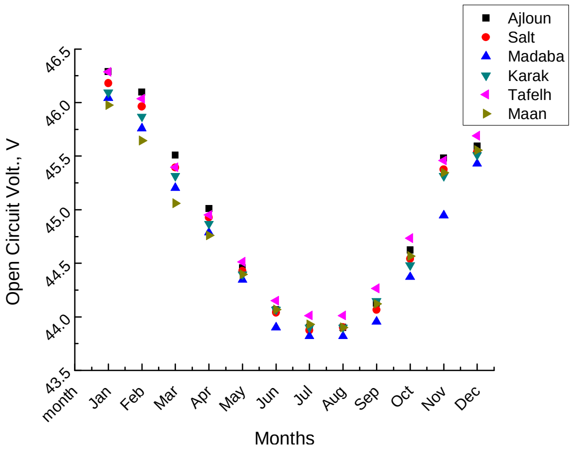

Figure 5: PV Module Average Open Circuit Voltage of the Six Selected Sites

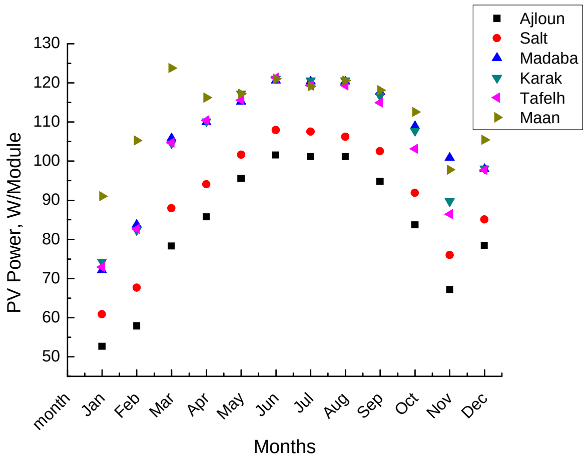

Figure 6: PV Module Power Output for the Six Selected Sites

By using equation number 1, the PV module power output can be calculated under the real weather criteria. Figure 6 present the output power from the PV module for the selected sites which are Ajloun, Salt, Madaba, Karak, Tafelh and Maanwith values of 102, 108, 121, 121, 121 and 121 W respectively.

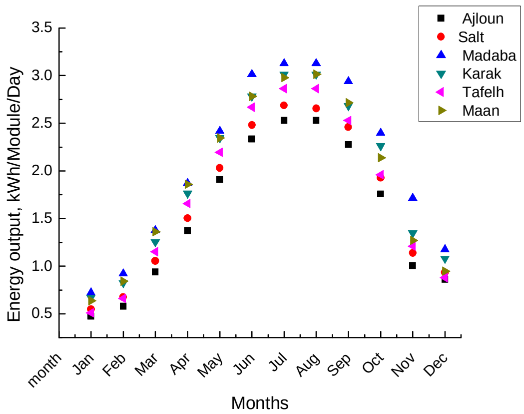

Figure 7: Daily PV Energy Output for the Selected Six Sites

The energy output as average daily amount as well average yearly amount is illustrated in figure 7 and 8, respectively. The max-average daily energy output of the selected sites can be extracted based on the figure 7 as 2.75 kWh

in average for all sites. While the min in an average of 0.6 kWh. The monthly average energy output is shown in the figure 8, and it is clear that the max energy output for the selected sites come in an average of 85 kWh and the min in an average of 20kWh.

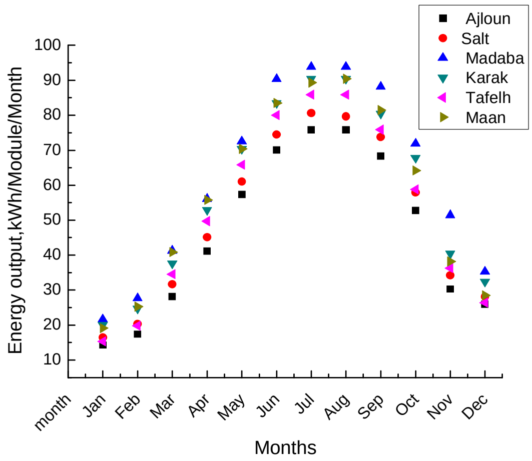

Figure 8: Monthly PV Energy Output for the Selected Sit Sites

For the selection of the optimum site for the PV investment, an accumulative energy output is calculated for the six selected sites. Figure 9 shows the accumulative energy output of the six selected sites with a total energy output of 550, 600 750, 700 625 and 750 kWh/year for the sites of Ajloun, Salt, Madaba, Karak, Tafelh and Maan respectively.

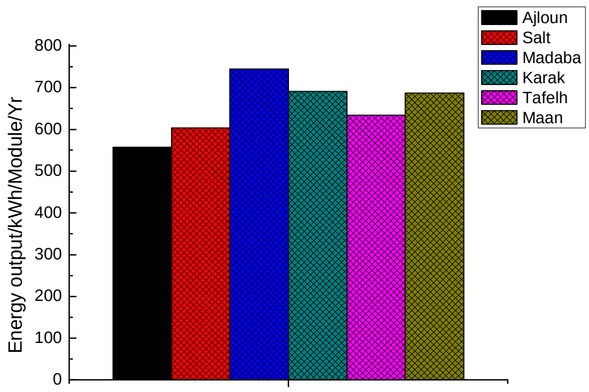

Figure 9: PVyearly Energy Output of the Selected Six Sites

CONCLUSIONS

In this investigation, PV module performance is studied for six selected sites in Jordan which are Ajloun, Salt, Madaba, Karak, Tafelh and Maan in order to find the best site for the PV applications. The yearly energy output of the selected sits is in an average of 700 kWh, but the best sites for the future investment in PV application were Madaba and Maan with an average of energy production of 700 kWh/year. While the worst site between the selected sites is Ajloun with an energy output of 550 kWh/year.

Overall, it can be summarized that the sites with the highest solar radiation have the max ability to generate more electricity from the PV module comparing to the sites with the lowest solar radiation. Form another point, the best sites selected for the PV application will have the lowest unfriendly emissions for the environment as the PV system is pollutant free, as it is found that Madaba and Maan is the best location among the selected six sites.

REFERENCES

1. *Al-omary, M., M. Kaltschmitt, and C. Becker, Electricity system in Jordan: Status & prospects. Renewable and Sustainable Energy Reviews, 2018. 81: p. 2398-2409.*
2. *Al-Ghandoor, A., Evaluation of energy use in Jordan using energy and exergy analyses. Energy and Buildings, 2013. 59: p. 1-10.*
3. *Al-Hamamre, Z., et al., Wastes and biomass materials as sustainable-renewable energy resources for Jordan. Renewable and Sustainable Energy Reviews, 2017. 67: p. 295-314.*
4. *Handri D.Ammari, S.S.A.-R.a.M.I.A.-N., Evaluation of wind energy potential and electricity generation at five locations in Jordan. Sustainable Cities and Society, 2015. 15: p. 135-143.*
5. *Ammari, H.D., S.S. Al-Rwashdeh, and M.I. Al-Najideen, Evaluation of wind energy potential and electricity generation at five locations in Jordan. Sustainable Cities and Society, 2015. 15: p. 135-143.*
6. *Alrwashdeh, s.S., Investigation of the energy output from PV racks based on using different tracking systems in Amman-Jordan. International Journal of Mechanical Engineering and Technology, 2018. 9(10): p. 687–69.*
7. *Alrwashdeh, S.S., The effect of solar tower height on its energy output at Ma'an-Jordan. AIMS Energy, 2018. 6(6): p. 959–966.*
8. *Alrwashdeh, S.S., Investigation of the energy output from PV racks based on using different tracking systems in Amman-Jordan. International Journal of Mechanical Engineering and Technology, 2018. 9(10): p. 687–694.*
9. *Alrwashdeh, S.S., et al., Improved Performance of Polymer Electrolyte Membrane Fuel Cells with Modified Microporous Layer Structures. Energy Technology, 2017. 5(9): p. 1612-1618.*
10. *Alrwashdeh, S.S., et al., Neutron radiographic in operando investigation of water transport in polymer electrolyte membrane fuel cells with channel barriers. Energy Conversion and Management, 2017. 148: p. 604-610.*
11. *Alrwashdeh, S.S., Map of Jordan governorates wind distribution and mean power density. International Journal of Engineering & Technology, 2018. 7(3): p. 1495-1500.*
12. *Alawneh, R., et al., Assessing the contribution of water and energy efficiency in green buildings to achieve United Nations Sustainable Development Goals in Jordan. Building and Environment, 2018. 146: p. 119-132.*
13. *Alrwashdeh, S.S., et al., In Operando Quantification of Three-Dimensional Water Distribution in Nanoporous Carbon-Based Layers in Polymer Electrolyte Membrane Fuel Cells. ACS Nano, 2017. 11(6): p. 5944-5949.*
14. *Alrwashdeh, S.S., et al., Investigation of water transport dynamics in polymer electrolyte membrane fuel cells based on high porous micro porous layers. Energy, 2016. 102: p. 161-165.*
15. *Mohammad A. Saraireh, F.M.A., and Saad S. Alrwashdeh, Investigation of Heat Transfer for Staggered and in-Line Tubes. International Journal of Mechanical Engineering and Technology 2017. 8(11): p. 476–483.*
16. *Saad S. Alrwashdeh, F.M.A., Mohammad A. Saraireh, Solar radiation map of Jordan governorates. International Journal of Engineering & Technology, 2018. 7(3).*
17. *Saad S. Alrwashdeh, F.M.A., Mohammad A. Saraireh, Henning Markötter,Nikolay Kardjilov, Merle Klages, Joachim Scholta and Ingo Manke, In-situ investigation of water distribution in polymer electrolyte membrane fuel cells using high-resolution neutron tomography with 6.5 µm pixel size. AIMS Energy, 2018. 6(4): p. 607–614.*

18. *Saad S. Alrwashdeh, H.M., Jan Haußmann, Joachim Scholta, André Hilger, Ingo Manke, X-ray Tomographic Investigation of Water Distribution in Polymer Electrolyte Membrane Fuel Cells with Different Gas Diffusion Media. ECS Transactions, 2016. 72(8): p. 99-106.*

19. *Saad S. Alrwashdeh, F.M.A., Wind energy production assessment at different sites in Jordan using probability distribution functions. ARPN Journal of Engineering and Applied Sciences, 2018. 13(20): p. 8163-8172.*

20. *Alrwashdeh, S.S., Assessment of Photovoltaic Energy Production at Different Locations in Jordan. INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH 2018. 8(2).*

21. *Afanasyeva, S., D. Bogdanov, and C. Breyer, Relevance of PV with single-axis tracking for energy scenarios. Solar Energy, 2018. 173: p. 173-191.*

22. *Bertrand, C., et al., Solar irradiation from the energy production of residential PV systems. Renewable Energy, 2018. 125: p. 306-318.*

23. *Senthil, R. A. M. A. L. I. N. G. A. M., Gupta, M. U. K. U. N. D., & Rath, C. H. I. N. M. A. Y. A. (2017). Parametric analysis of a concentrated solar receiver with Scheffler reflector. Int J Mech Prod Eng Res Dev, 7(5), 261-268.*

24. *Guichi, A., et al., A new method for intermediate power point tracking for PV generator under partially shaded conditions in hybrid system. Solar Energy, 2018. 170: p. 974-987.*

25. *Ince, U.U., et al., Effects of compression on water distribution in gas diffusion layer materials of PEMFC in a point injection device by means of synchrotron X-ray imaging. International Journal of Hydrogen Energy, 2018. 43(1): p. 391-406.*

26. *Sun, F., et al., Complementary X-ray and neutron radiography study of the initial lithiation process in lithium-ion batteries containing silicon electrodes. Applied Surface Science, 2017. 399: p. 359-366.*

27. *Alrwashdeh, S.S., Comparison among Solar Panel Arrays Production with a Different Operating Temperatures in Amman-Jordan. International Journal of Mechanical Engineering and Technology, 2018. 9(6): p. 420–429.*

28. *Hrayshat, E.S. and M.S. Al-Soud, Solar energy in Jordan: current state and prospects. Renewable and Sustainable Energy Reviews, 2004. 8(2): p. 193-200.*

29. *Kandemir, E., N.S. Cetin, and S. Borekci, A comprehensive overview of maximum power extraction methods for PV systems. Renewable and Sustainable Energy Reviews, 2017. 78: p. 93-112.*

30. *Krishna Kumar, N., V. Subramaniam, and E. Murugan, Power Analysis of non-tracking PV system with low power RTC based sensor independent solar tracking (SIST) PV system. Materials Today: Proceedings, 2018. 5(1, Part 1): p. 1076-1081.*

31. *Li, C., D. Zhou, and Y. Zheng, Techno-economic comparative study of grid-connected PV power systems in five climate zones, China. Energy, 2018.*

32. *Mohapatra, A., et al., A review on MPPT techniques of PV system under partial shading condition. Renewable and Sustainable Energy Reviews, 2017. 80: p. 854-867.*

33. *Paital, S.R., et al., Stability improvement in solar PV integrated power system using quasi-differential search optimized SVC controller. Optik, 2018. 170: p. 420-430.*

34. *Samimi-Akhijahani, H. and A. Arabhosseini, Accelerating drying process of tomato slices in a PV-assisted solar dryer using a sun tracking system. Renewable Energy, 2018. 123: p. 428-438.*

35. *Shabani, M. and J. Mahmoudimehr, Techno-economic role of PV tracking technology in a hybrid PV-hydroelectric standalone power system. Applied Energy, 2018. 212: p. 84-108.*

36. Yang, Y., et al., 2 - Power electronic technologies for PV systems, in Advances in Grid-Connected Photovoltaic Power Conversion Systems, Y. Yang, et al., Editors. 2019, Woodhead Publishing. p. 15-43.
37. Yazdanifard, F. and M. Ameri, Exergetic advancement of photovoltaic/thermal systems (PV/T): A review. Renewable and Sustainable Energy Reviews, 2018. 97: p. 529-553.
38. Al-Najideen, M.I. and S.S. Alrwashdeh, Design of a solar photovoltaic system to cover the electricity demand for the faculty of Engineering- Mu'tah University in Jordan. Resource-Efficient Technologies, 2017. 3(4): p. 440-445.
39. Hammad, M., M.S.Y. Ebaid, and L. Al-Hyari, Green building design solution for a kindergarten in Amman. Energy and Buildings, 2014. 76: p. 524-537.
40. Al-Hamamre, Z., et al., Assessment of the status and outlook of biomass energy in Jordan. Energy Conversion and Management, 2014. 77: p. 183-192.
41. Al-Ghandoor, A., et al., Energy and exergy utilizations of the Jordanian SMEs industries. Energy Conversion and Management, 2013. 65: p. 682-687.
42. Al-Soud, M.S. and E.S. Hrayshat, A 50 MW concentrating solar power plant for Jordan. Journal of Cleaner Production, 2009. 17(6): p. 625-635.
43. Portal, C.C.K. http://sdwebx.worldbank.org/climateportal/index.cfm. 2018.
44. LG. https://www.lg.com/us/commercial/documents/spec-72cell-340-012516.pdf. 2018.
45. Beckman, J.A.D.a.W.A., Solar Engineering of Thermal Processes. Fourth Edition ed. Soalr Energy. 2013, Hoboken, New Jersey: John Wiley & Sons, Inc.